32

Components of Visual Orienting

Michael I. Posner
University of Oregon
Eugene, Oregon, USA
and
Good Samaritan Hospital
and Medical Center
Portland, Oregon, USA

Yoav Cohen
University of Oregon,
Eugene, Oregon
USA

ABSTRACT

A peripheral visual cue produces an orienting of attention that facilitates detection of targets in the cued area. Following a shift of attention away from the cued area, targets at that location are handled less efficiently than at other places. We demonstrate this inhibitory effect, show that it arises from the sensory information present in the cue, and discuss its relationship to shifts in eye position and its functional significance in the process of orienting of attention. We indicate how the inhibitory effect accounts for the difficulty in demonstrating attentional orienting in situations where attended information arises from a single spatial position. We believe that the components of visual orienting provide a model experimental system where important components of cognitive tasks can be linked to neural systems.

INTRODUCTION

One of the goals of cognitive psychology is to account for complex cognitive phenomena in terms of simpler elementary mental operations that can, in turn, be related to neural systems. In the area of attention, some progress has been made toward this goal through the study of component processes involved in the detection of simple sensory events (Posner, 1980). It is our hope that an analysis of orienting to luminance changes may aid us in understanding general mechanisms that underlie the ability to bring visual information to consciousness in tasks such as reading. Recently, this general approach to attention has been reviewed in some detail (Posner, 1982). In the present chapter we wish to report a new inhibitory component of visual orienting and discuss how the components of covert orienting are related to eye movements and to the study of neural systems and natural cognition.

Previous work in this field (Eriksen & Hoffman, 1973; Mountcastle, 1978; Posner, 1980; Wurtz, Goldberg, & Robinson, 1980) has emphasized improvements in information processing when attention is oriented to a location in visual space. This improvement can occur at positions away from fixation even with no overt change in eye position or other motor systems. This work has already begun to produce important evidence on the neural systems that support enhancements in target detection at attended positions (Mesulam, 1981; Mountcastle, 1978; Posner, Rafal, & Cohen, 1982; Wurtz et al., 1980). In the second section of this chapter we briefly review evidence of facilitation when cues concerning where in space a target will occur are introduced prior to each trial.

In the third section we present new evidence of an inhibitory effect that follows orienting to a peripheral cue and yet does not appear to depend upon the present commitment of attention. We show that the origin of this spatially selective inhibitory effect is sensory rather than attentional, but that it interacts with the direction of attention in important ways.

Although neither the facilitation nor the inhibition accompanying stimulus events depend upon overt movements, we explore their relationship to eye movements in the fourth section. In the final section we summarize evidence linking these component processes both to neural systems and to higher-level cognitive functions.

FACILITATION

For a long time it was believed that the detection of sensory events could only be studied in a complex or cluttered visual field or if the events were obscured or masked by noise. According to signal detection theory, the noise and signal distributions must overlap to separate the collection of sensory evidence from the formulation of a decision.

This theoretical view was supported by evidence that knowledge of where in visual space a stimulus might occur did not lead to an improvement in detection under conditions in which the field was empty and the signal well above threshold (Grindley & Townsend, 1968; Mertens, 1956; Mowrer, 1941). In 1973, however, Erikson and Hoffman presented cues to subjects indicating where in an otherwise empty visual field a single letter would occur. They found significant facilitation of the reaction time to that cued event. Following this result, a number of other investigators (Bashinski & Bachrach, 1980; Jonides, 1981; Posner, 1980; Posner, Nissen, & Ogden, 1978) used central and peripheral cues to direct attention to various places in the visual field and showed that even under the most austere conditions of empty visual fields and clear, bright stimuli, various dependent variables showed improved efficiency when subjects were cued to the location of the event. These experiments indicate quite clearly that covert orienting can facilitate performance. This improvement in target processing can occur without eye movements (Posner, 1980), can be directed either from central or peripheral cues (Jonides, 1981), and can be tightly time-locked to the occurrence of the cue (Shulman, Remington, & McLean, 1979). It is useful to liken this time-locked shift of attention in the direction of cues to the movement of a spotlight across the visual field. Indeed, the analog nature of those movements of attention (Posner, 1980; Shulman et al., 1979) encouraged this metaphor.

An important aspect of these new studies of orienting is that they use a cue introduced before each trial to provide a basis for subjects to orient. This methodology is quite different from that used by most early investigators (Mertens, 1956; Mowrer, 1941), who used blocks of trials where one particular spatial position was high probability and who failed to obtain effects of orienting.

Indeed Posner, Davidson, & Snyder (1980) demonstrated that changing from a task in which an orienting cue is presented prior to each trial to one involving blocks of trials in which one particular event was highly probable eliminated the facilitation obtained from orienting. In the blocked condition we studied reaction time to lights at four places when they were equally probable for a block of trials and blocks in which one light was made highly probable (0.79). We compared this situation with a condition in which a central cue before each trial indicated what position contained the probable light. Obviously, a spotlight metaphor or an information theory model would predict essentially an equal advantage of the light with the high probability in both conditions. Quite to our surprise, we found that the blocked paradigm produced little evidence of facilitation, while the cued design produced highly significant costs and benefits. Studies prior to

1973 almost invariably used blocked designs, while those since have usually used cued designs. The use of cued designs helps to explain why it is now so commonly accepted that an expected spatial position will be facilitated. We believe it is now possible to explain why the blocked design fails to produce the expected facilitation.

INHIBITION

A possible reason for the failure of the blocked design to produce significant benefits from orienting lies in an inhibitory effect produced by a peripheral cue or target. We have found that having received a stimulus at a given spatial position, information from that place is inhibited in speed of processing when compared with other control positions. The following experiments demonstrate this inhibitory effect.

Basic Paradigm

Our subjects fixate at the center of a cathode ray tube on a central box of 1° flanked by two peripheral boxes 8° to the left and right of the fixation box (see Fig. 32.1). The trials begin with a 150 msec brightening of the outline of one of the two peripheral boxes selected at random. A bright target (0.1° filled square) occurs at the center of a box, either 0, 50, 100, 200, 300, or 500 msec after the brightening. The target is usually in the center box (0.6), but it may occur on either side (0.1 probability on each side). Catch trials in which no target is presented occur with probability of 0.2. Subjects are instructed to respond to the target as quickly as possible by pressing their single key. Eye movements are monitored using EOG electrodes. In the experiments of this section, subjects are instructed to keep eyes fixated, and trials with detectable movements are excluded. In later experiments we explore the effects of eye movements.

The first experiment involving six subjects each ran for two days. Our expectation was that the cue would summon attention. Thus, the cued side would have an initial reaction-time advantage over the uncued side. However, because targets occurred mainly at the center, subjects would be expected to keep attention there insofar as they were able to. Thus, any advantage of the cued side as a result of attention should be lost as attention was returned to the center. We would then be able to compare the two sides to observe the consequences of previous peripheral cue on target detection latencies once attention was withdrawn.

The results conformed well to our expectations; these are shown in Fig. 32.2. Targets on the cued side show an advantage in RT for the first 150

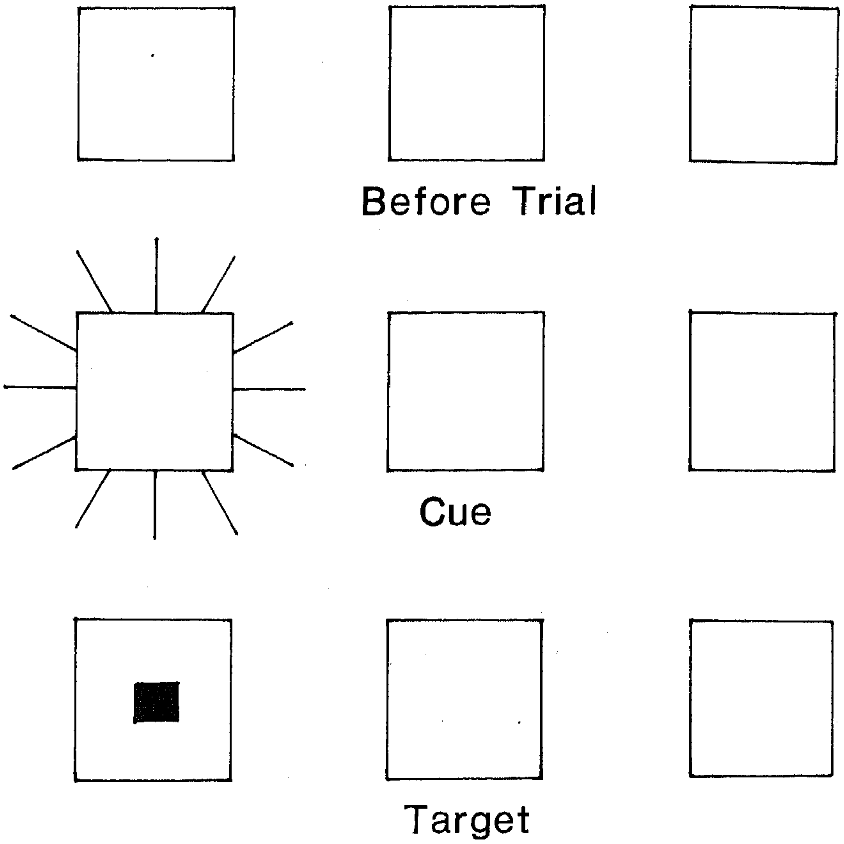

FIG. 32.1. Basic paradigm. Top panel is before a trial. Subject fixates at central box. A brightening of the outline of one peripheral box initiates a trial (middle panel). A small but bright target appears in the center of one of the boxes to which a response is required.

msec. This is replaced by a clear inhibition of target RT on cued side in comparison to the uncued side after about 300 msec. The center remains fastest throughout, as might be expected because of its high probability and its foveal location. It would appear that the early advantage to the cued side is followed by a subsequent inhibition.

We have since replicated this basic effect with a simpler method, in which a peripheral brightening first summons attention, which is then returned to fixation by a central brightening (Cohen, 1981). This method produced a highly reliable early facilitation followed by inhibition (see Fig.

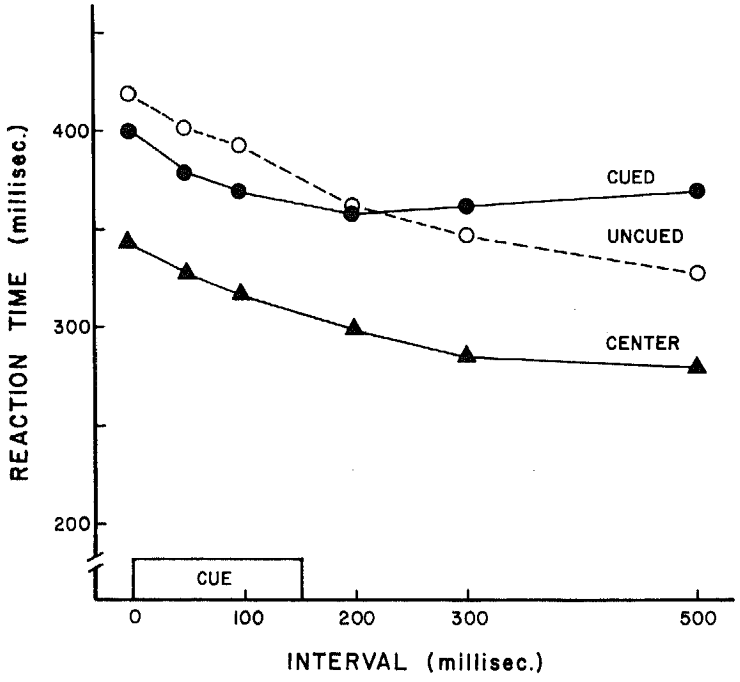

FIG. 32.2. Reaction time as a function of interval following a peripheral cue for cued and uncued and foveal targets.

32.3).[1] With this method, shifts of attention can occur with no manipulation of probability. We have found evidence of facilitation even when targets occur at the cued position on only 0.1 of the trials, with the remaining trials being distributed over noncued peripheral positions, the center, and catch trials. The inhibition effect appears to last about 1 to 1.5 sec following the deflection of attention to the center. Thus, our results

---

[1] It should be noted in Fig. 32.3 that the cued side is relatively flat, while the uncued side shows a reduction in RT with time. It might be thought that the uncued side is facilitated rather than the cued side being inhibited. However, in most experiments a cue produced a reduction in RT with SOA due to a general alerting change (see Fig. 32.2). Thus the relatively flat function for the cued side indicates that something is preventing the usual decrease of RT with SOA. The importance of general alerting to the shape of this change is shown even more strongly in Fig. 32.4. In this case, subjects ignored the cue, and no general alerting effects are found. The uncued targets show a flat function over time, while the cued targets increase in RT over time. However, irrespective of the differing overall shapes in Figs. 32.2, 32.3, and 32.4, the early facilitation and late inhibition of the cued side with respect to the uncued side is always found.

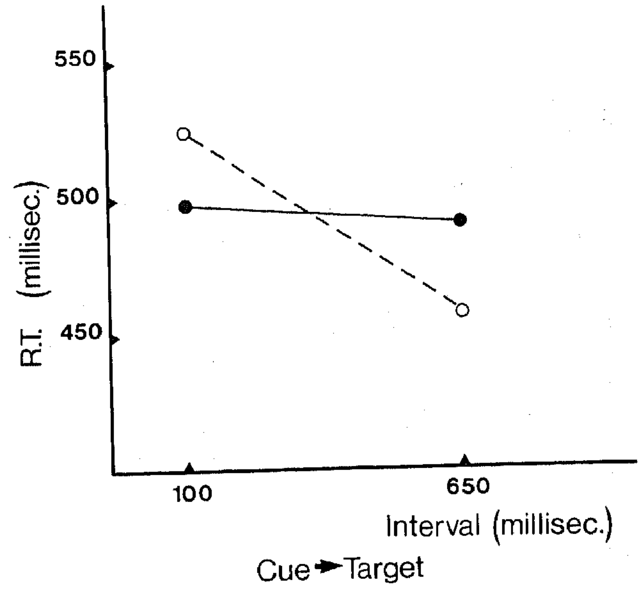

FIG. 32.3. Reaction time as a function of interval following a peripheral cue for targets on the cued side (solid line) and on the uncued side (dotted line).

suggest that the inhibition effect occurs quite automatically and without the need for any deliberate strategy on the part of the subject.

Several views about the origin of this inhibition occurred to us: (1) it could be due to the fact that inhibition results from the use of only two alternative positions. In many two-alternative reaction-time tasks, alternations are faster than repetitions. Failing to find a target at the cued position shortly after the cue, the subject may guess that the target is more likely to occur at the other position. (2) Inhibition could be a result of the movement of attention away from the cued stimulus in order to return to the center. If subjects move attention back toward the center, they may have more difficulty in reversing it back to the cued position than in allowing attention to continue to the uncued side. (3) Some part of the pathway from the cued location may be reduced in efficiency by the cuing. This could occur because of the sensory cue itself, or because of the covert orienting as a result of the sensory cue.

Four Alternative Experiments

To test the first two possible explanations, we used a central box and four peripheral boxes, each 5° from the central box. Targets occurred at the central box with a probability of 0.6 and in each of the peripheral boxes with equal probability of 0.1. Otherwise, the experiment was the same as the previous one.

When we compare the cued position with the mean of the other three positions, there is an initial advantage for the cued side replaced by an inhibition, as before (see Fig. 32.2). When the side opposite the cue is compared with the two orthogonal positions at right angles to the cue at 500 msec SOA, it is clear that the opposite position is no faster than the two orthogonal positions, while all three positions are faster than the cued one. These results show that the inhibition is not limited to the two alternative cases and that a target in the direction of the assumed attention movements from cue to center is not necessarily at an advantage over other positions in the visual field. The results thus eliminate the possibility that the inhibition is associated with the use of only two alternatives. It also shows that inhibition is relative to all other positions in the visual field, and that the mirror-image location is not special (Singer, Zihl, & Poppel, 1977).

Dimming and Double Cuing

In order to examine the role of sensory factors in this phenomenon, we introduced cuing either by brightening the cued box or by dimming it. If the facilitation effect is not due to forward brightness enhancement, we should get similar facilitation in both cases. To investigate further the sensory versus attentional character of facilitation and inhibition, we introduced trials in which both peripheral positions were cued simultaneously. To ensure that attention was at the fovea for late targets, we brightened the center position 300 msec following the initial cue. No targets were presented at the center, but they occurred with equal probability in the two peripheral boxes either 80 msec or 500 msec following the first cue. In accordance with the previous results, we expected the cued side to show facilitation in the former condition and inhibition in the latter.

The results are shown in Fig. 32.4[2]. Data from the single-cue trials

---

[2] In this experiment the use of both brightening and dimming and of single- and double-cued trials caused subjects to lose awareness of the cue as occurring at the start of each trial. Subjectively, it was as though one simply looked for the target and ignored the various cues. In conformity with this impression, the usual improvement in RT with SOA (alerting effect) was not found. The uncued conditions were flat, and the cued conditions increased with SOA. Despite the subjective feeling of having ignored the cue and the lack of alerting effect, the early facilitation and late inhibition remain as in other studies.

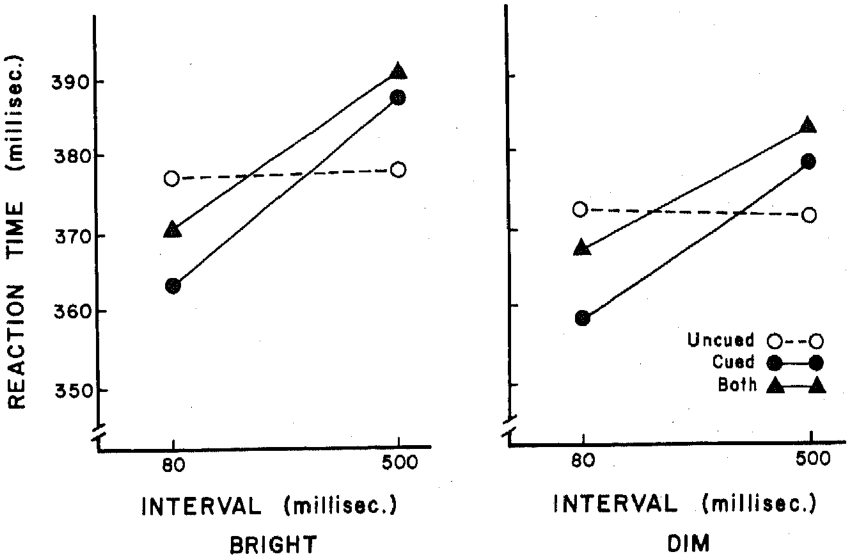

FIG. 32.4. Reaction time as a function of interval following a cue for cued, uncued, and double cueing conditions when the cue is either brightening of a peripheral box (left panel) or dimming of the box (right panel).

conform well to our expectations. Regardless of whether the cue is introduced by brightening or dimming, the cued side is initially faster than the uncued and is slower for probes 500 msec following the cuing. This suggests that the facilitation effect is not due to any kind of brightness enhancement.

The results of the double-cue trials are interesting. The cued sides are not significantly facilitated when compared to the uncued side in single-cue trials. In accordance with previous work (Posner et al., 1980, Exp. V) we believe that attention cannot be split to the two sides when both are cued. However, the inhibition in the double-cue trials is as great as that found for single-cue trials. The finding of significant inhibition without significant facilitation suggests that inhibition does not arise from attentional orienting but from the energy change present at the cued position.

Since we found slight but not significant facilitation effects in the double-cued condition, it is not possible for us to be certain that orienting is unnecessary for obtaining inhibition. Indeed, Maylor (unpublished) has found evidence that orienting may be necessary for inhibition to occur. In the next study we consider whether orienting of attention is a sufficient basis for inhibition when no peripheral information is presented.

Arrow Experiment

To check further on the role of sensory information and attentional orienting in facilitation and inhibition, we used a central cue rather than a peripheral cue to indicate where to attend. Each trial began with an arrow that occurred above the central fixation box. On half the trials the target was presented 450 msec following the arrow. If the target occurred at this point, it was on the side cued by the arrow 0.8 of the time and on the uncued side 0.2 of the time. These probabilities were to provide the subject with incentive to shift attention to the side indicated by the arrow. If no target had been presented 600 msec after the arrow, the center box was brightened to return attention to the fixation. Following the center brightening, targets were most likely to occur at the center (0.6) and had equal probabilities of occurring at either of the two peripheral boxes (0.2). These late targets occurred either 950 or 1250 msec following the start of the trial. The use of these time intervals was to ensure that subjects had time to shift attention to the side cued by the arrow for early targets and had returned attention to the center for late targets.

The results are shown in Fig. 32.5. The cued side shows the expected facilitation following the arrow cue. This is in accord with many other

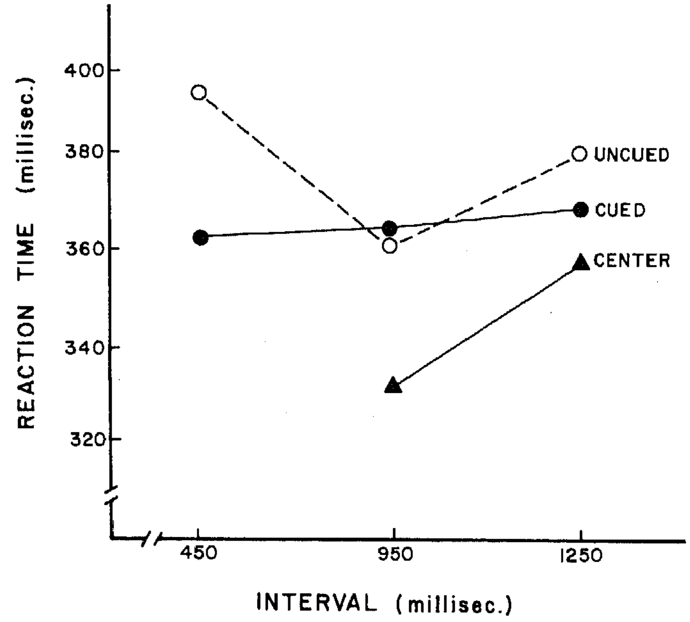

FIG. 32.5. Reaction time as a function of interval following a central arrow cue for cued, uncued, and center targets.

results obtained with central cues. However, there is clearly no inhibition following the return of attention to the center. These results show that facilitation can be obtained either from peripheral or from central cues. However, the inhibition effect does not occur if the cue is a central one. Orienting of attention is not a sufficient condition for the inhibition effect. The results of this study and the double-cue experiment suggest that inhibition depends primarily or perhaps exclusively upon the sensory information.

Sources of Inhibition

The experiments summarized above show that a peripheral visual stimulus both summons attention and serves to inhibit the processing of further information at that position in space. These two effects appear to be independent and may cancel each other out. Thus if attention is not drawn away from the cued location, no net inhibition is found. Immediately after a cue there is usually a net facilitation, and no net inhibition appears to occur unless attention is summoned away from the cue.

What is the source of inhibition? One possibility is that it arises because of a need to inhibit a motor response to the cue. This apparently is not the source of the inhibition effect. If, instead of using a cue, subjects are given a block of trials in which they must respond by pressing a key to each successive target, one can examine RT to trial $N+1$ as a function of the spatial location of the target on trial N. We have found a negative sequential dependency such that trial $N+1$ has a longer RT if on the same side as trial N (Posner, Cohen, Choate, Maylor, & Hockey, in press). A similar inhibition has also been observed in recent work by Maylor (unpublished). In these studies, subjects make a response to each event, and yet a spatial inhibition effect is still found.

A second possible contributing source to the inhibition effect might be the same mechanisms as those involved in forward masking. Presentation of light energy at the cued position seems to delay the processing of an event, which shows up as a net inhibition once attention is withdrawn. Inhibition could arise if the physical presentation of light energy somehow masked the occurrence of new energy. We cannot rule out the involvement of some mechanisms of forward masking in these experiments. However, the usual time course of forward masking is in the range of 100 msec, while we get clear effects of inhibition between 500 and 1000 msec after the occurrence of the cued event. Moreover, many theories of forward masking argue for the importance of the averaging of light energy from the mask and the stimulus, while we have shown that either an increase or a reduction of cue light energy will produce the inhibition effect.

Another potential phenomenon to which our inhibition effect might be related is habituation of the vertex-evoked potential in cases where two successive events are presented (Davis, Osterhammel, Wier, & Gjerdingen, 1972). The time course of this habituation of vertex-event-related potentials is rather long and could be within the range of effects reported in this paper. However, our attempt to record the vertex-event potential to targets following the presentation of cues has shown no evidence for this habituation effect.

The inhibition effect reported in this paper thus does not appear to occur as the result of the need to prevent responding to the cued event, does not seem to be identical with forward masking, and does not seem to involve habituation of the event-related potential to the target. We see this inhibition as arising from the presentation of any visual stimulus.[3] If the stimulus also summons attention, the inhibition may be masked by attention.

RELATION TO EYE MOVEMENTS

In this section we investigate the relation of the facilitation and inhibition effects to the movement of the eyes. Posner (1980) argued for a functional relationship between eye movements and covert spatial attention. We now propose a more detailed view of how facilitation and inhibition function together in natural situations. This view links the function of the inhibition effect closely to eye-movement preferences.

In previous work (Posner, 1980) it was found that facilitation of reaction times in the neighborhood of the target for an eye movement occurs about 200 msec before the eyes move. Nonetheless, there is also considerable evidence supporting the independence of facilitation arising from covert attention from eye movements. First, facilitation does not depend on moving the eyes to the stimulus but occurs when the subjects keep their eyes fixed. Second, it is possible to dissociate the direction of the eyes from the movement of attention sufficiently for the eyes to move in one direction while attention moves in the other (Posner, 1980). Third, we have shown that with monocular viewing the direction of eye movements is biased in favor of the temporal visual field (Posner & Cohen, 1980). This effect is so powerful in newborns that their eyes seem to move only in the direction of temporal visual stimuli (Lewis, Maurer, & Milewski, 1979).

---

[3] Strictly speaking, we do not have completely convincing evidence that light energy itself is sufficient for the inhibition effect. We know that orienting of attention is not sufficient (arrow experiment), and the lack of a significant facilitation effect in the double-cue experiment inclines us to the belief that it is unnecessary as well.

Since the newborn has well-developed collicular but poorly developed cortical control, this suggests that the advantage of the temporal over the nasal visual field in eye movements is a sign of control via mid-brain systems. Shulman (in press) has shown that this difference, so powerful in controlling eye movements, has very little effect upon the latency of covert orienting. These points all show that the facilitation effect is not closely related to the eye-movement system.

Coordinates of the Facilitation Effect

We have been interested in the spatial coordinates in which attention is mapped during saccades. We considered three possibilities: Attention could be locked to fixation and thus move with the fovea; it could move independently of the fovea to a position defined by retinal coordinates; or it could remain in the same environmental position, thus staying at the same physical position on the cathode ray tube as the eyes move.

Cohen (1981) studied the location of facilitation during eye movements. These studies are presented in detail elsewhere (Cohen, 1981), but it is important to review the method and conclusions. In one experiment, Cohen presented subjects with a display of six boxes arrayed in two horizontal lines of three. Subjects fixated in the top center box at the start of each trial. A signal was given that instructed them to move their eyes to the center box in the bottom row (7° downward). Either simultaneously or prior to the signal to make an eye movement, one of the two peripheral boxes in the upper row was brightened. Target events could occur with equal probability in any of the four peripheral boxes. No targets were presented at the foveal position.

One could propose three outcomes for this experiment. If attention moved from the fixation at the top row to fixation at the bottom row, one would expect no difference in reaction time between targets occurring on the cued and uncued side. Since attention would be located at the bottom center, there should be no advantage for any peripheral position. The second possibility would be that attention remains at the environmental location that had been cued—that is, at the cued position in the upper row. This would predict that there would be facilitation, or faster reaction times at the cued position than the uncued position in the upper row, but RTs at the two bottom-row positions would be equal. Finally, attention could move to the cued location as defined in retinotopic coordinates by following the eyes downward but moving to the position directly below the cued peripheral position in the upper row. In this case, RT would be faster at the position in the bottom row on the cued side than the uncued side, and the top row targets would have equal RTs.

The evidence supported attention movement in retinotopic coordinates.

Reaction time was significantly less on the side of the bottom row below the cue. Since many perceptual effects reported in the literature seem to be mapped in environmental rather than retinotopic coordinates, this result is of considerable interest. Cohen also found that the tendency of attention to travel to the bottom row with the eyes could be reduced or eliminated by making the top row highly probable. This suggests that subjects have considerable voluntary control over where facilitation will occur and fits well with the idea of covert orienting of attention as a basis for facilitation. The idea that facilitation works in retinal *coordinates* should not be confused with the view that the facilitated effect is located on the retina. We do not favor a retinal location for the effect, since facilitation occurs when the cue and target were presented to different retinas by use of a stereoscope (Cohen, 1981).

There is evidence that many maps in the visual system are retinotopic (Cowey, 1979). Treisman (Treisman & Gelade, 1980; Treisman & Schmidt, 1982) has speculated that one of the important functions of attention is to tie together attributes of objects that may be separately located within different visual maps. It is possible that the facilitation effect results from attention to a location within these maps.

Spatial Coordinates of the Inhibition Effect

It is also possible to determine the relation between inhibition and eye movements. Our previous experiments establish that inhibition cannot depend entirely on eye movements, since it occurs with eyes fixed. Since all our previous experiments had been with eyes fixed, it is possible that an eye movement would actually reduce or eliminate the inhibition effect. We wished to determine whether inhibition would occur when the eyes moved and, if it did, whether it was mapped in environmental or retinotopic coordinates. The next two experiments are designed to study that issue.

Back-and-Forth Experiment. In the first experiment, subjects fixated the center of a screen on which a display of three boxes were present (as in Fig. 32.1). Each trial began with the presentation of a small digit in one of the two peripheral boxes. The digit served as a peripheral cue, instead of the center brightening we had used previously.[4] Subjects were required to

---

[4] Cohen (1981) used brightening of a peripheral box followed by brightening of the central box as cues in a back-and-forth eye-movement experiment in other ways identical to the one described in this section. He found the same results as found in this experiment, where the peripheral cue is a digit rather than a brightening of the box. The agreement between these two studies indicates that the exact physical configuration of the peripheral light change matters little.

read the digit and return their eyes to the center when it brightened. We monitored performance in order to make sure the subjects fixated the digit. Since the digit was too small to read when the subject's eyes were fixated in the center, we had good assurance of fixation at the periphery. We gave subjects 600 msec to read the digit before it disappeared and the center brightened for 200 msec. We waited either 600 or 1450 msec following the center brightening before presenting targets with equal frequency at each of the two peripheral positions. On 20% of the trials no target was presented. The results are shown in Fig. 32.6. There is a strong inhibitory effect at the cued location. The effect is present at both center brightening to target intervals and thus lasts at least for 1.5 sec.

Right-Angle Experiment. In the previous experiment, the cue was presented at the same retinal and environmental location as a target when it was on the cued side. Thus, while the experiment shows quite clearly that the inhibitory effect can be found when subjects move their eyes, it does not indicate the spatial coordinates of the inhibitory effect. To examine this phenomenon in more detail, we set up an experiment, which is illustrated in Fig. 32.7. We wished to present the target at a spatial location that had been cued by environmental coordinates but at which there had been no retinal stimulation. To do this, we required subjects to make three eye movements. They first moved from the central top box to a lower box in which a digit was presented (EM1). The next digit was presented in the top box on the side on which they were fixated, and they moved to it (EM2). After reading the digit at that position, they moved to the center when it was brightened. This sequence of movements ensures that when the eyes are fixated in the center no cue had occurred at the retinal position of the digit in the top row. This position has environmental but no retinal stimulation. The exact timing of the eye movements is described below.

At the beginning of each trial, the subject's eyes were fixated on the center of the screen. At the start of the trial, a small digit was presented at the left or right of the screen in the bottom row. Subjects moved their eyes to read this digit. After 500 msec, a single digit was presented directly above the first digit. They moved their eyes from the first to the second digit and once again read the digit. After another 500 msec the center box was brightened, and subjects moved their eyes to the center. Target events were introduced 600 and 1450 msec after the center brightening. The first target occurred relatively soon after the subjects had reached the center. The subjects' mean reaction time for an eye movement was approximately 250 msec, so that there were very few trials when subjects had not reached the center by the time the target occurred.

Figure 32.7 indicates that the targets on the cued side (e.g., side of the digit) occur at retinal positions that have never been stimulated. This is illustrated in the bottom half of the figure for the sequence of eye

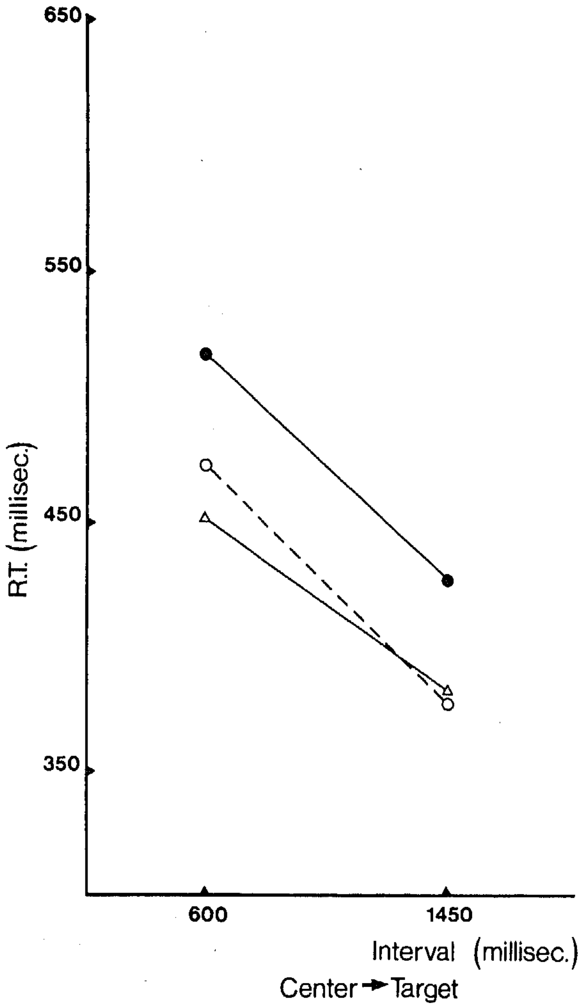

FIG. 32.6. Reaction time in an experiment in which subjects move their eyes from the center to a peripheral location (cued side) and back. Targets follow the return eye movement and occur on the cued side (filled circles) opposite the cued side (dotted line) or at the fovea (triangle).

movements shown in the top half of the figure. Consider the case illustrated in Fig. 32.7, where the digits and target occur on the left. The first digit occurs below and to the left of fixation and also at fixation once EM1 has been made. The second digits occur initially directly above fixation and at fixation following EM2. The center brightening occurs to

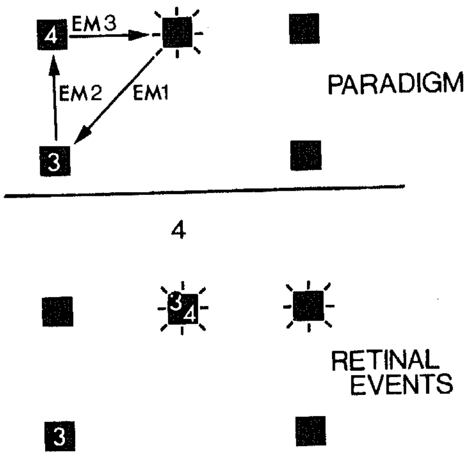

FIG. 32.7. Paradigm for an eye movement study in which subjects move their eyes from the center to the lower left or right (EM1), then to the upper row (EM2) and following a signal to the center (EM3). Lower panel indicates the retinal locations of the previous stimulation at the point where the eyes are centered.

the right of fixation and at fixation following EM3. The lower portion of Fig. 32.7 superimposes all the events at the correct retinal locations as they are when the center is fixated. It is clear that the retinal location corresponding to the physical location of the digit on the left side has not been stimulated.

The results are very clear-cut (see Fig. 32.8). The subjects show a strong inhibitory effect for the early target, which seems to decay in the 1000 msec between the early and late targets. In any case, the significant inhibition that occurs immediately after the subjects return to central fixation indicates that the inhibition must be at least primarily mapped in environmental, not retinotopic coordinates.

Theory

The inhibitory effect seems at least as strong when subjects move their eyes as when the eyes remain fixed. Quantitatively, the effect is actually larger, but that may be due to the general amplification of reaction times that occurs when the subject must both make an eye movement and respond manually to probe events. We cannot be sure from the magnitude of the inhibition effect how closely the effect is associated with the eye-movement system.

We have now identified two effects that occur when a peripheral cue is

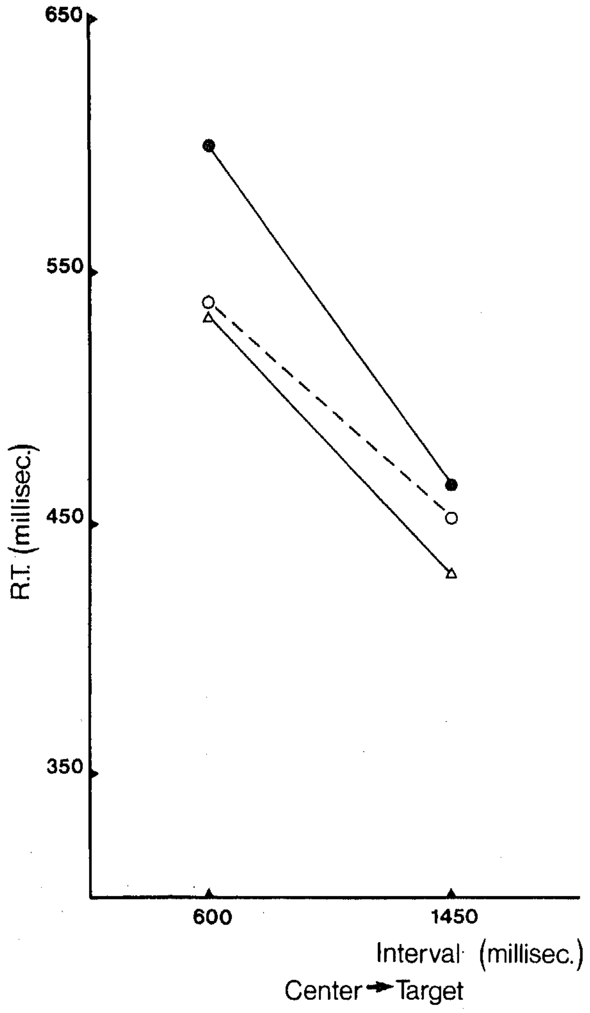

FIG. 32.8. Reaction time in the experiment portrayed in Fig. 32.7 as a function of time following the center cue for targets on the previously fixated side (filled circles), previously unfixated side (dotted line) and at the fovea (triangles).

presented. We believe that these two effects overlap in time and that the efficiency of detection results from their joint influence. The first is facilitatory; we think of it as central because it can be initiated either by a symbolic cue indicating where in space the target is likely to occur or by a peripheral cue. We argue that the facilitation is caused by a covert orienting of attention in the direction of the cue. Orienting may be induced by central peripheral cues (Posner, 1980), or it may occur prior to an eye movement (Posner, 1980) or as a result of a probability manipulation (Posner, et al., 1982). If orienting is induced by a peripheral cue, we have shown that the facilitation moves with the eyes in retinotopic coordinates.

The second effect is an inhibitory one that serves to reduce the efficiency of target detection. We can show a clear crossover in reaction time between cued and uncued locations only when we summon attention away from the cued location back to the neutral fixation point. Following the center brightening, there is a clearly longer RT at the formerly cued location. However, we believe that the inhibition builds up over the same time interval as facilitation but is simply masked by the larger facilitation resulting from covert orienting. The inhibition effect is not central in origin, since it occurs only with a peripheral cue. It depends on a change in light energy (brightening, or dimming) at the cued location. The inhibition effect occurs whether the eyes move to the cued location or not. The double-cue study suggests it may happen even in the absence of covert orienting toward the cue. The inhibition effect lasts for a long time; under the conditions of the back-and-forth eye movement experiments it lasts at least 1.5 sec. When the eyes move, the inhibition effect remains at the environmental position at which the light change occurred.

How can we understand the functional significance of a central facilitatory effect that uses retinotopic coordinates and a peripheral inhibitory effect depending on light energy that is in environmental coordinates?

Our current view is that the facilitation effect is meant to improve the efficiency of target detection within a fixation.[5] It selects out an area of space that is important for the organism. If no eye movement occurs, that area can be processed more efficiently than other areas of the visual field. In many cases, of course, subjects will move their eyes to the cued area, thus increasing the acuity there. We have shown that subjects have considerable voluntary control over the facilitation effect, so that in cases where the eyes move it would be most usual for attention to go to the new

---

[5] There is some controversy over exactly how this improved efficiency in RT takes place. Shaw (Chapter 7, this volume) argues that it is the result of a criterion shift not of an improvement in detectability. As we see it, efficiency changes due to cues arise because of the priority that signals from cued locations have for access to higher level systems including awareness. Cueing effects have been shown to affect threshold detection as well as RT and to improve *d'* (Bashinski & Bachrach, 1980). However, the use of any statistic as a measure of discriminability is based upon a particular theory. What seems important to us is that the improvement does not depend upon a particular dependent variable (e.g., RT), occurs even when the probabilities would favor noncued locations, and is related systematically to critical events such as eye movements.

foveal position. This occurs because the fovea is drawn to the area because of its significance. Under the conditions of our eye-movement experiments where the fovea never gets a target, we are able to show that attention is related to retinotopic coordinates; but presumably, under the more usual conditions of natural vision, attention moves in advance of the eyes but returns to fovea as the eyes move.

We believe that the inhibition effect evolved to maximize sampling of the visual environment. Once the eyes move away from the target location, events that occur at that environmental location are inhibited with respect to other positions. This would reduce the effectiveness of a previously active area of space in summoning attention and serve as a basis for favoring fresh areas at which no previous targets had been presented. The long-lasting nature of inhibition (1.5 sec or more) seems to be about the right length to ensure that the next movement or two will have a reduced probability of returning to the former target position.

This view links the facilitation effect to orienting of attention within the fixed visual field, while the inhibition effect is related to favoring novel positions as the targets for future eye movements. It is also possible to see the inhibition effect as favoring release of attention from a spatial position, so that concentration at any single position does not become too great. However, the fact that inhibition depends upon a peripheral visual change (see arrow experiment) and can last for such a long time after an eye movement argues for the importance of its role in directing future covert and overt attentional acts.

The organization of facilitation and inhibition outlined above represent an exquisite functional adaptation to the needs of the visual world. There has been much discussion within psychology and physiology about the use of retinotopic and environmental coordinates for the mapping of visual phenomena (Breitmeyer, Kropfl, & Julesz, 1982; Davidson, Fox, & Dick, 1973; Jonides, Irwin, & Yantis, 1982; Irwin, & Yantis, 1982). Physiological analysis has usually stressed retinotopic maps, while subjective experience indicates environmental mapping. Our finding of the close relationship of both types of coordinate systems may be useful in a better understanding of how retinotopic maps relate to environmental experience.

NEURAL SYSTEMS AND COGNITION

As we outlined in the introduction, there has been some convergence between the study of the visual orienting in human beings by methods of mental chronometry and the study of physiological mechanisms of attention by means of single-cell recording. Both techniques have shown selective facilitation occurring prior to eye movements and when important information is presented eccentric to the current fixation. In both methods there is time-locking of the facilitation, so that in the superior colliculus, facilitation occurs at cells whose receptive field is in the neighborhood of the target for an eye movement about 150 msec before the eye movement actually begins (Wurtz et al., 1980). Similarly, improvements in reaction time and threshold detection occurs 200 msec before the eyes begin to move (Posner, 1980; Remington, 1980).

Another area of convergence involved the localization of attentional mechanisms. Wurtz et al. (1980) have reported that selective enhancement of single cells occurs in two locations in the nervous system for spatial-orienting tasks. These are the superior colliculus, where it occurs only prior to eye movements, and the posterior parietal lobe.

Our results with patient populations suffering from progressive supranuclear palsy and from right parietal lesions (Posner et al., 1982) have shown that these two areas produce effects upon covert spatial.orienting. The effects are not identical. Paralysis of the saccadic eye movement system produced by degenerative mid-brain disease seems to affect the latency of orienting in the direction in which the eye-movement system is most impaired, but none of our patients failed to detect the signals. Moreover, covert orienting was possible even in directions to which no saccades could be made.

Lesions of the parietal lobe also seem to leave intact the ability of subjects to use cues to facilitate performance on both the damaged and undamaged side. However, such patients show very large deficits in performance when attention is drawn to the side ipsilateral to the lesion and the target occurs contralateral to the lesion. Under some circumstances there can be complete exclusion of targets from consciousness (extinction).

Our results involve areas of the brain in which selective enhancement occurs, but they suggest that neither the superior colliculus not the parietal lobe should necessarily be seen as the seat or location of attention. Since neither collicular nor parietal lesions prevent the affect of cues on target detection latencies, it appears that neither type of lesion destroys attentional effects. Rather, the parietal lesion in particular appears to make it difficult for a signal arising contralateral to the lesion to produce successful orienting. This occurs whenever attention is misdirected to the side ipsilateral to the lesion, whether by central or peripheral cues. It is striking that when attention is misdirected patients with a parietal lesion can fail to detect targets that would cause them no problems when attention is correctly cued. This result suggests that what shows up as a small latency difference between cued and uncued sides in normals can in cases of brain injury produce a complete exclusion of the target from the subject's awareness. Such findings support our general view that the orienting system we are studying is a critical operation in our awareness of visual signals.

There is also evidence of an inhibitory effect on individual neural cells that occurs with the presentation of a second signal in the visual field occupied by a target (Rizzolatti, in press; Wurtz, Richmond, & Judge, 1980). This effect resembles the cost in RT we find when attention is cued to a position other than the target. Our explanation for the RT effect is that orienting to the cue reduces the efficiency of taking in information from the target. It is possible that single-cell inhibition effect is related to the inhibitory effect discussed in this chapter. If animals covertly orient to a new signal, it is possible that cells responding to the target would now exhibit the inhibition that accompanies any change in light energy. Wurtz et al. (1980) argue that their cellular inhibition effect is sensory, not attentional, in origin in much the same way we have discussed here. Nonetheless we believe our inhibition effect plays a role in determining the location of future covert and overt orienting. In light of our finding that the function of the inhibitory effect described in this chapter appears to relate closely to eye movements, it is interesting that the single-cell remote inhibitory effect has been reported primarily in the superior colliculus. It will be important to determine whether the same functional model of the role of facilitation and inhibition in orienting that we have reported here can also be applied fruitfully at the cellular level.

Links to Cognition

It is also important to investigate the manner in which covert shifts of spatial attention influence performance in more natural tasks of cognition. Since this volume is most interested in the study of language, it seems reasonable to ask whether covert attentional effect may be involved in spatial effects found during reading. Of course, reading involves frequent overt shifts of the eyes (Rayner, Chapter 5, this volume), but it is also possible to examine spatial effects with the eyes fixed.

LaBerge (in press) has attempted to document such covert attentional shifts in reading letters and words. He required subjects to perform a primary task of classifying either whole words or individual letters within words. On some trials subjects also had to respond to probe events occurring at differing spatial positions. LaBerge found that for letter tasks there was a sharp spatial gradient in probe reaction times favoring the position at which the critical letter was introduced. For whole words the position of the probe with respect to the word made little difference. LaBerge concluded that subjects could widen or narrow the beam of attention from a single character in the letter task to five characters in the word task.

A similar method was employed by Chang (1981) to study the perceptual assymetries in the visual field while reading. It is well known from the work of Rayner (Chapter 5, this volume) that during the reading of English, the effective visual field is larger to the right of fixation than it is to the left. Recently Pollatsek, Bolozky, Well, and Rayner (1981) reported that while reading Hebrew, the spatial asymmetry is in the opposite direction.[6] At least three theoretical accounts for this asymmetry are possible. First, it might arise because the predominant eye movements in English are left to right and in Hebrew right to left. Second, it might also arise as a consequence of differences in hemispheric organization for the two languages. Finally, it might arise because of an entirely covert internal scan that proceeds from left to right in English and from right to left in Hebrew.

To test this last idea, Chang (1981) presented subjects with stories one or two words at a time while they remained fixated at a central position. The crucial word of the story was centred around the fixation point. On rare occasions, Chang probed by omitting the word and instead presenting an arrow 1°, 3°, or 5° to the right or left of fixation for 40 msec. He studied the reaction time to report the direction of this arrow as a function of the reading task provided to the subject. Chang's results showed that when reading right-side-up English, arrows were processed better to the right of fixation, while when reading upside-down English, arrows were processed better to the left of fixation. This asymmetry in perceptual span was not due to eye movements, since there were none. The switch in asymmetry obtained by merely turning the words upside-down argues against a hard-wired hemispheric interpretation. It suggests, instead, that there is an internal scanning process that goes from left to right in correctly oriented English words and from right to left in upside-down words. Although the reading was generally slower and more effortful with upside-down words, the use of comprehension questions at the end of the passages indicated that the subjects were reading for comprehension and not merely looking at the words without understanding the story they told. Thus, there is some reason to believe that subjects in the experiment were engaging in normal reading. Both the Chang and the LaBerge studies indicate that methods are available for investigating the spatial distribution of attention during reading even when no eye movements occur.

Of course, many ideas about attention go beyond the study of spatial attention that have been the focus of this paper. Spatial attention has the

---

[6] Although there has been much dispute about whether there is a left-field bias for Hebrew readers when reading individual words, the Pollatsek et al. (1981) study seems clear-cut in showing an asymmetry under conditions of continuous reading with eye movements.

advantage of providing a model that allows study of the relationship between covert and overt components of orienting and provides links between humans and other animals. Attention to higher-level codes and to meaning obviously plays the major role in cognitive tasks such as reading. There is some reason to believe that an understanding of spatial attention will provide useful cues to the role of attention in other aspects of language processing (Posner & Friedrich, in press).

ACKNOWLEDGMENTS

The experiments reported here were performed jointly by the two authors. The format of the lecture, however, is the responsibility of the first author. The research was supported by a grant BNS 7923527 from the National Science Foundation to the University of Oregon. We thank Lisa Choate, Mark Irmscher, and Jonathan Vaughan for their assistance in this research.

REFERENCES

Bashinski, H. S., & Bachrach, V. R. Enhancement of perceptual sensitivity as the result of selectively attending to spatial locations. *Perception and Psychophysics*, 1980, *28*, 241–248.

Breitmeyer, B. G., Kropfl, W., & Julesz, B. The existence and role of retinotopic and spatiotopic forms of visual persistance. *Acta Psychologica*, 1982, *52*, 175–196.

Chang, F. *Distribution of attention within a single fixation in reading: Studies of the perceptual span*. Unpublished doctoral dissertation, University of Oregon, 1981.

Cohen, Y. *Internal and external control of orienting*. Doctoral dissertation, University of Oregon, 1981.

Cowey, A. Cortical maps and visual perception. *Quarterly Journal of Experimental Psychology*, 1979, *31*, 1–17.

Davidson, M. L., Fox, M. J., & Dick, A. O. Effect of eye-movements on backward masking and perceived location. *Perception and Psychophysics*, 1973, *14*, 110–116.

Davis, H., Osterhammel, P. A., Wier, C. C., & Gjerdingen, D. Slow vertex potentials: Interactions among auditory, tactile and visual stimuli. *EEG & Clinical Neurophysiology*, 1972, *33*, 537–545.

Eriksen, C. W., & Hoffman, J. E. The extent of processing of noise elements during selective encoding from visual displays. *Perception and Psychophysics*, 1973, *14*, 155–160.

Grindley, C. G., & Townsend, V. Voluntary attention in peripheral vision and its effects on acuity and differential thresholds. *Quarterly Journal of Experimental Psychology*, 1968, *20*, 11–19.

Jonides, J. Voluntary versus automatic control over the mind's eye. In J. Long & A. Baddeley (Eds.), *Attention and performance IX*. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1981.

Jonides, J., Irwin, D. E., & Yantis, S. Integrating visual information from successive fixations. *Science*, 1982, *215*, 192–194.

LaBerge, D. The spatial extent of attention to letters and words. *Journal of Experimental Psychology: Human Perception and Performance*, in press.

Lewis, T. L., Maurer, & Milewski, A. E. The development of nasal detection in young infants. *ARVO Abstracts*, 1979, 271.

Maylor, E. Unpublished studies of inhibition.

Mertens, J. J. Influence of knowledge of target locations upon the probability of observation of peripherally observable test flashes. *Journal of the Optical Society of America*, 1956, *46*, 1069–1070.

Mesulam, M. M. A cortical network for directed attention and unilateral neglect. *Annals of Neurology*, 1981, *10*, 309–324.

Mountcastle, V. B. Brain mechanisms for directed attention. *Journal of the Royal Society of Medicine*, 1978, *71*.

Mowrer, O. H. Preparatory set (expectancy): Further evidence of its "central" locus. *Journal of Experimental Psychology*, 1941, *28*, 116–133.

Pollatsek, A. Bolozky, S., Well, A. D., & Rayner, K. Asymmetries in the perceptual span for Israeli readers. *Brain and Language*, 1981, *14*, 174–180.

Posner, M. I. Orienting of attention. The VIIth Sir Frederic Bartlett Lecture, *Quarterly Journal of Experimental Psychology*, 1980, *32*, 3–25.

Posner, M. I. Cumulative development of attentional theory. *American Psychologist*, 1982, *37*, 53–64.

Posner, M. I., & Cohen, Y. Attention and the control of movements. In G. E. Stelmach & J. Requin (Eds.) *Tutorials in motor behavior*. Amsterdam: North Holland, 1980.

Posner, M. I., Cohen, Y., Choate, L., Maylor, E., & Hockey, G. R. J. Sustained concentration: Passive filtering or active orienting? In S. Kornblum & J. Requin (Eds.), *Preparatory States and Processes*. Hillsdale, N. J.: Lawrence Erlbaum Associates, in press.

Posner, M. I., Davidson, B. J., & Snyder, C. R. R. Attention and the detection of signals. *Journal of Experimental Psychology: General*, 1980, *109*, 160–174.

Posner, M. I., & Friedrich, F. Attention and the control of cognition. In S. Friedman & Klivington (Eds.), *The brain, cognition and education*. New York: Academic Press, in press.

Posner, M. I., Nissen, M. J., & Ogden, W. C. Attended and unattended processing modes: The role of set for spatial location. In H. L. Pick, & I. J. Saltzman (Eds.), *Modes of perceiving and processing information*. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1978.

Posner, M. I., Rafal, R. D., & Cohen, Y. Neural systems control of spatial orienting. *Philosophical Transactions of the Royal Society London*, 1982, *B 298*, 187–198.

Remington, R. W. Attention and saccadic eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, 1980, *6*, 726–744.

Rizzolatti, G. Mechanisms of selective attention in mammals. In J. P. Ewert, (Ed.), *Advances in vertebrate neuroethology*. In press.

Shulman, G. L. Capture analysis: The role of the temporal field. *Acta Psychologica*, 1982, in press.

Shulman, G. L., Remington, R. W., & McLean, J. P. Moving attention through visual space. *Journal of Experimental Psychology: Human Perception and Performance*, 1979, *5*, 522–526.

Singer, W. & Zihl, J., & Poppel, E. Subcortical control of visual thresholds in humans: Evidence for modality specific and retinotopically organized mechanisms of selective attention. *Experimental Brain Research*, 1977, *29*, 173–190.

Treisman, A. M., & Gelade, G. A feature integration theory of attention. *Cognitive Psychology*, 1980, *12*, 97–136.

Treisman, A. M., & Schmidt, H. Illusory conjunctions in the perception of objects. *Cognitive Psycholory*, 1982, *14*, 107–141.

Wurtz, R. H., Goldberg, M. E., & Robinson, D. L. Behavioral Modulation of visual responses in the monkey: Stimulus selection for attention and movement. *Progress in Psychobiology and Psychology*, 1980, *9*, 43–83.

Wurtz, R. H., Richmond, B. J., & Judge, S. J. Vision during saccadic eye movements. III. Visual interactions in monkey superior colliculus. *Journal of Neurophysiology*, 1980, *43*, 1168–1181.